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14. ABSTRACT

An integrated, time-dependent, stochastic model for predicting mine burial in littoral waters is presented. The model is designed to account for impact burial of mines and coupled post-impact burial processes (scour, sand ridge migration, and liquefaction) by integrating currently available deterministic models that predict these burial processes. Operational Navy databases and oceanographic modeling output from the United States Naval Oceanographic Office (NAVOCEANO) are used to set up the initial bathymetric and sediment conditions and provide the temporal driving burial forces. The model uses Monte Carlo simulations to provide stochastic burial predictions based on mine geometry and various deployment scenarios. Temporal changes in burial conditions may be displayed on a regional map.

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Regional Mine Burial Prediction Using Monte Carlo and Deterministic Methods

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Summary

An integrated, time-dependent, stochastic model for predicting mine burial in littoral waters is presented. The model is designed to account for impact burial of mines and coupled post-impact burial processes (scour, sand ridge migration, and liquefaction) by integrating currently available deterministic models that predict these burial processes. Operational Navy databases and oceanographic modeling output from the United States Naval Oceanographic Office (NAVOCEANO) are used to set up the initial bathymetric and sediment conditions and provide the temporal driving burial forces. The model uses Monte Carlo simulations to provide stochastic burial predictions based on mine geometry and various deployment scenarios. Temporal changes in burial conditions may be displayed on a regional map.

Introduction

The Office of Naval Research (ONR) and the Naval Research Laboratory (NRL) are currently conducting a joint program to improve capabilities for mine burial prediction. These programs are developing and testing models for the various burial processes (such as impact burial, scour, sandbar migration and liquefaction) using a field experimental approach. A major goal of this effort is production of a model usable by the operational Navy that integrates different processes contributing to mine burial and gives temporal and spatial uncertainty for the predictions.

We have developed a Monte Carlo approach in an effort to meet this goal. This model, called Monte Carlo Mine Burial Prediction (MCMBP), is designed to produce a prediction of mine burial for any region of the world that is covered by databases and modeling output at NAVOCEANO (Table 1). The simulation ingests these data at the front end to set up initial conditions and driving forces needed by deterministic mine burial models to directly compute burial for a large number of mines. As the name of the model implies, an estimate of uncertainty in the prediction is determined by analyzing the burial states obtained from repeating this process a large number of times at each mine location.

Although MCMBP is being designed to use NAVOCEANO resources, it has the flexibility to incorporate input from other databases, models or direct real-time measurements if they are available. We describe the model in further detail below.

Model Description

Mine burial processes can be placed in two categories: impact burial and post-impact burial. The strategy used by MCMBP is to first calculate impact burial based on mine characteristics, bathymetry and sediment data. Then, using a time stepping methodology,

Table 1: Partial list of Navy environmental data usable for mine burial predictions.

Databases	
Bathymetry	DBDB-V (Digital Bathymetric Database)
Sediment	Sediments 2.0
Ocean Modeling	
Waves	SWAN (Simulating Waves Nearshore)
Currents	NLOM (Navy Layered Oceanographic Model)
Tides only	PC-Tides

temporal burial is calculated from the post-impact processes. Random variability is added to the physical properties of the mine and release kinematics at each mine drop (Monte Carlo simulation).

The software is programmed in MATLAB and controlled by a graphic user interface (GUI). This GUI is used to specify the region of interest for which the mine burial prediction is to be made, upload simulated or empirical data for the geotechnical properties of the region, ingest a 1-D or gridded time-series of oceanographic conditions, control mine seeding initial conditions and number of trials, trigger execution of the burial process models, and denote the output product type. Models for the various burial processes ingest the input data to compute burial for the process they simulate. These models are contained in separate modules that can be updated or replaced as better models for the processes are produced. The output may then be written to file or displayed in a mapping product which shows percent burial for the period of time covered by the oceanographic time series data. In the discussion below, we describe in more detail the current modules used for the simulating impact and subsequent burial processes and how they are operated.

A. Impact Burial

Execution of the impact burial module is illustrated in Fig. 1. Currently, the kernel from the IMPACT28 [1, 2] simulation is used to calculate impact burial. (The stand-alone version of IMPACT28, written in Quick BASIC, has a GUI and a mine database for the end user to run the model. These aspects have been removed and the input requirements altered so that the kernel can be used iteratively in a Monte Carlo simulation. The remaining code has also been translated into MATLAB.) This module calculates the motion of the mine as it falls through the air, crosses the air/water interface (taking cavitation effects into account), continues through the water column and burrows into the sediment. Calculating the velocity of the mine and it's dynamics as it falls requires knowledge of the altitude above the water that the mine was dropped; the geometric, inertia and initial kinematic properties of the mine; and the water depth, density, and temperature. (Wave action and currents are assumed to have a negligible effect on impact burial.) The geotechnical data needed to calculate sediment burrowing are sediment density and bearing strength expressed as a function of layer depth. These data, however, need to be obtained from regional observations, or inferred from the NAVOCEANO sediment database, Sediments 2.0.

Figure 2 displays the GUI controls for specifying these inputs. Random variability of the initial condition of the mine characteristics and deployment strategy and, to a small

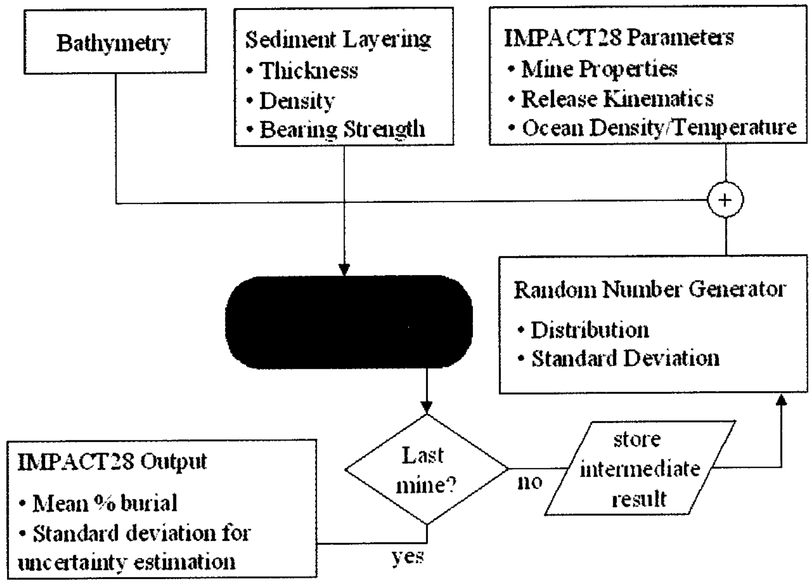

Fig. 1: Flow chart for the impact burial module. The parameters and the random number generator are controlled by the GUI shown in Fig. 2 below. Random variability is added at each iteration to the mine parameters and then passed to the IMPACT28 module with bathymetry and sediment layering.

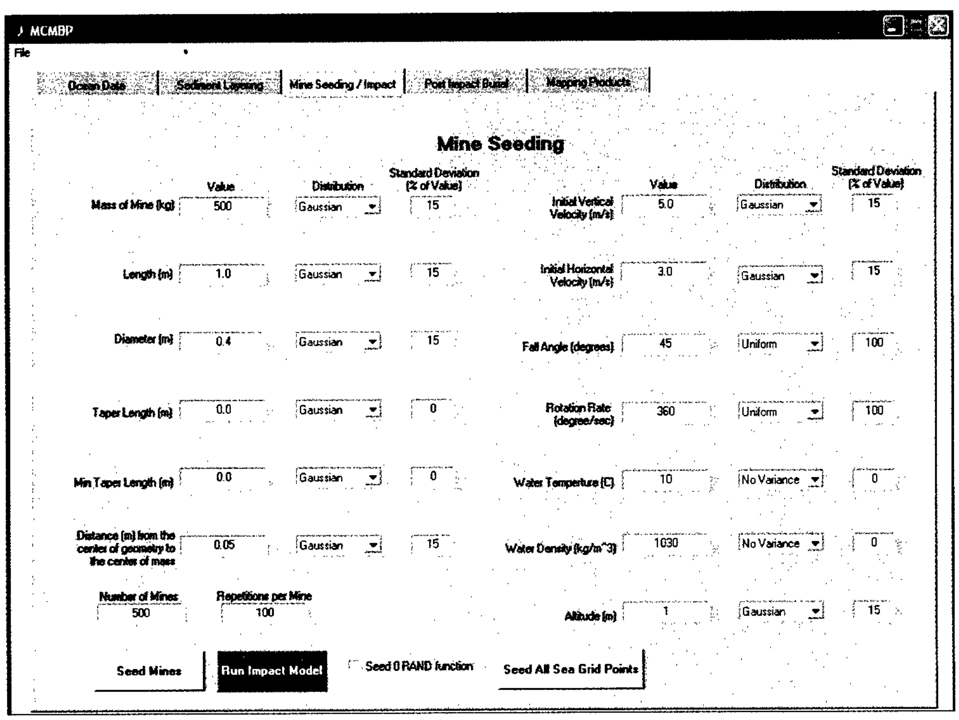

Fig. 2: GUI controls for setting initial conditions on mine geometry, dynamics and variability of the parameters. Bathymetry and sediment database ingest is controlled from the "Ocean Data" panel. Geological layers are specified in "Sediment Layering". Subsequent burial and visualization controls are under "Post Impact Burial" and "Mapping Products", respectively.

extent, oceanographic conditions (water temperature and density) also may be applied as desired. Once these data are uploaded and the initial conditions are set, the user then specifies the number of mines to be deployed over the area of interest and the number of trials per deployment before executing the module from the GUI. Output from this model gives the final geometry of the mine at the bottom, including the amount protruding above the sediment interface. From these data the amount of burial can be calculated. The location and burial results are then written to a file, which are then passed to the subsequent burial module of the simulation.

B. Subsequent Burial

Execution of the subsequent burial module is illustrated in Fig. 3. In addition to the location and initial burial of the mines, the sediment type and bathymetry are passed to this module from the impact burial part. These data, along with wave action (significant wave height and period) and currents, are needed for post-impact burial calculations. The later two are obtainable, respectively, from SWAN and NLOM (or if tides are all that need to be considered for currents, PCTIDES may be used instead) model outputs. The subsequent burial module must be repeated for each mine position.

Subsequent processes that have been modeled include scour, based on Friedrichs's implementation [3] of the HR Wallingford equations [4]; sand ridge migration from

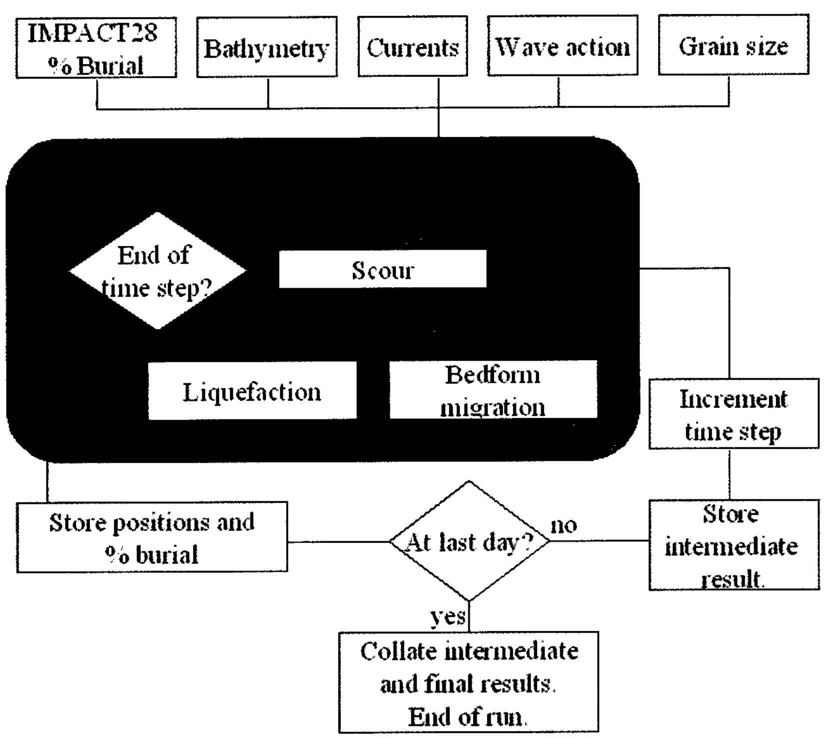

Fig. 3: Flow chart for execution of the subsequent burial module. Burial results from the IMPACT28 module illustrated in Fig. 1 are passed into the module, along with the other data illustrated. Subsequent burial processed act on burial of the mine at a time in a cyclic, iterative manner until the end of the time step is reached. Intermediate results are stored for each time time until the end of the time series data is reached.

Mulhearn's model [5]; and liquefaction based on the work of Sakai et. al. [6]. These models were designed to operate independent of other processes; however, in nature, we assume that these processes effect one another. Coupling between these processes is approximated using a "turn-based" approach: each time step is subdivided into smaller evenly spaced time-steps, and the different processes act iteratively on the mine one at a time until the end of the larger time period is reached. During this iterative process, the oceanographic conditions are assumed to be constant.

At each interval of the oceanographic time-series data, the intermediate burial result may be stored so that a time history of the burial may be inspected. An upper confidence interval may be estimated by repeating the calculation at two standard deviations above the mean initial burial, the highest confidence curve of the oceanographic data and the lowest potential median grain size (vice-versa for the lower confidence interval).

Preliminary Results

The Monte Carlo simulation was run to hindcast mine burial for the Martha's Vineyard area from April 5 to May 28 in 2002. During this time, NRL deployed an instrumented mine [7] off the southern coast of Martha's Vineyard in 12 meters of water, while recording orbital velocity and wave period [8] (currents also were recorded, but are assumed to be insignificant to overall burial). Bathymetry and sediment data were uploaded from the databases given in Table 1 into the model for the area from 41.0N to 41.5N by 71.0W to 70.0W. The Sediments 2.0 database reports that the entire region is sand with a median grain diameter of 350 microns. In this case, all impact burial is assumed to be only 10%.

For this case, the orbital velocity and wave period recorded at the mine (Fig. 4) is assumed to be the same for all grid points in the area (we are working to compare gridded wave data from SWAN with experiment). Since scour is the only subsequent process that will be used, the amount of burial is only given by the amount of wave friction at the mine, which according to linear wave theory, strengthens as wave height increases and as depth and wave period decreases [9]. Hence, significant scour occurs in shallower regions and at times of increase wave heights. Figure 5 shows the predicted burial under these assumptions at the end of the NRL deployment period. As expected, the overall burial correlates closely with bathymetry.

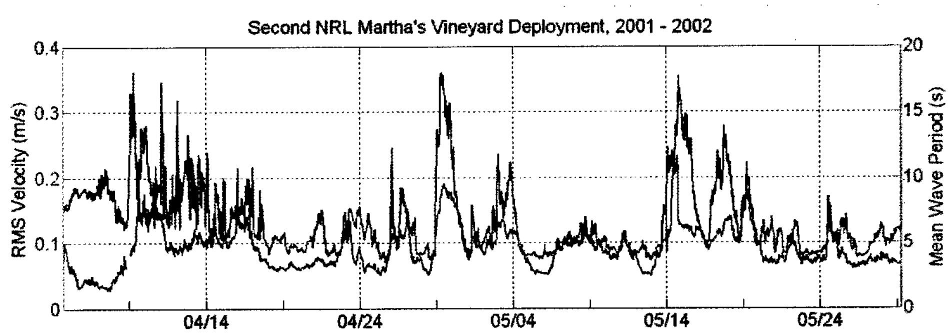

Fig. 4: RMS orbital velocity and mean wave period for the ONR/NRL instrumented mine burial deployment in the spring of 2002.

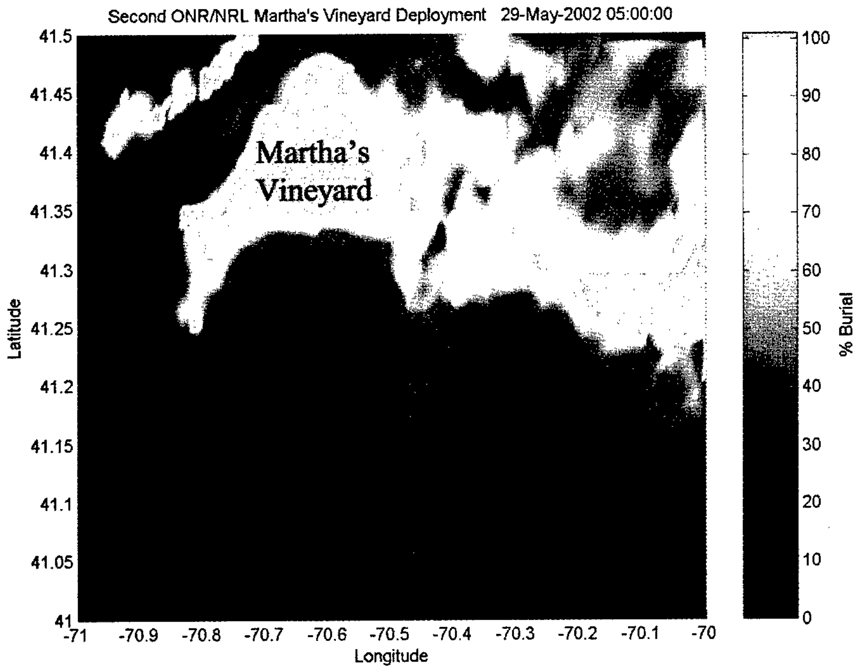

Fig. 5: Mine burial prediction near Martha's Vineyard for May 29, 2003 for mines deployed April 5, 2003. Prediction is based on scour alone and 10% initial burial. Gray coloring corresponds to land.

Discussion

Execution of the program can be shortened by recognizing the type of sediment that is contained underneath a mine and returning a preset value for burial that is appropriate for that sediment type without running the burial module. In regions that are sandy, very little impact burial occurs. Hence, the impact burial module can be programmed to set the burial at a small initial burial for this sediment, as was done for the Martha's Vineyard hindcast. Conversely, muddy regions will be absent of scour and sandbar migration influences and have a cohesiveness that prevents liquefaction. Thus, the subsequent models may be programmed to return zero burial for this case.

The Monte Carle simulation can be computationally intensive. For approximately 1,700 Monte Carlo mine drops in the Martha's Vineyard area, the simulation took three hours (impact and subsequent burial simulation) on a 2.53 GHz, Pentium-4 PC running Windows 2000 with 1 GB of RAM. Each of these mine drops involved only one trial per position and upper and lower confidence intervals were not computed. As of now, the model may need to be run on a robust workstation or a supercomputer if the statistics need to be generated from a large sample of mines drops.

A strength of the model, however, is that it does not require *a priori* training since its predictions are based on direct computation from deterministic models. Thus, it is capable of producing forecasts for mine burial based on up-to-date ocean modeling forecasts and geotechnical information. It also can be useful for training Expert Systems [10], which rely on archived probability tables, as updated geotechnical and oceanographic data becomes available or new threat areas are identified.

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